CHAPTER 5

A SCREENING OF ALTERNATIVE FUELS FOR POSSIBLE USE IN HAWAII'S GROUND TRANSPORTATION SECTOR

5.1 SCREENING CRITERIA

5.1.1 INTRODUCTION

This Chapter assesses fuel options for Hawaii in the context of state energy goals. It is important to note that in this analysis, the alternative fuels are not being compared with conventional fuels. The purpose of this screen is to compare the alternative fuels to each other to assess which appear, given what we know at this time, to best meet the state's energy objectives. Fuels that pass the screen are examined in more detail in this study.

5.1.2 DESCRIPTION OF THE SCREENING CRITERIA

In cooperation with the Department of Business, Economic Development and Tourism (DBEDT), criteria were developed for the various alternative fuel options[1] in order to assess their relative consistency with Hawaii's transportation energy goals. These criteria combine formal goals of the state with the understanding of DBEDT staff, based on the history of legislative, agency, and public efforts to define state energy goals. The criteria are now described.

Criterion 1. Offers energy security to Hawaii

A relatively large displacement of petroleum fuel, on the order of 40 percent, would afford some energy security to the State of Hawaii (Kaya, 1993). Alternative fuels provide some energy security through petroleum displacement, but the fuels may be further distinguished as either possible to produce from local resources or requiring importation.

Fuels that may be produced in substantial volumes from local resources at competitive prices (perhaps with government subsidy as justifiable based on economic benefits to the state) best satisfy this criterion. Local production at "competitive prices" implies that imports are not likely to capture substantial market share.

Non-petroleum imported fuels may provide increased supply security and price stability. Methanol, natural gas, and LPG (liquified petroleum gas) could be imported from either the mainland or from a number of other sources that may be more politically stable than the Middle East, which dominates oil markets. However, non-petroleum imported fuels rank lower under this criterion than fuels which may be produced from local resources.

[1] References to "fuels" and "fuel options" also include technology options, such as electric and hybrid-electric vehicles.

Criterion 2. Offers environmental benefits (including safety)

Vehicles utilizing alcohols, biodiesels, electricity, hydrogen, natural gas, and LPG may be designed to achieve lower rates of pollutant emissions than vehicles fueled with gasoline or diesel. One of the primary reasons for manufacturers to market alternative fuel vehicles (AFV) is increasingly stringent air quality regulations. In designing, building, and operating low- or zero-emission AFVs, manufacturers are preparing to meet requirements for AFVs imposed by Federal, state, and municipal governments across the nation. AFVs have reduced (sometimes to zero) evaporative and tailpipe emissions compared to conventionally fueled vehicles.

Many alternative fuels offer other benefits as well. For example, spill hazards are greatly reduced or eliminated with many alternative fuels in comparison to gasoline and diesel. The safety codes that apply to alternative fuel production, distribution and on-board systems are generally more than sufficient to assure that public safety is no more threatened by any alternative fuel than by conventional fuels, when the fuels are handled in accordance with appropriate standards and practices.

Although comparing the relative environmental, health, and safety effects of each fuel option is a complicated task, in general, all of the alternative fuel options being discussed in this study have the potential to offer environmental, health, and safety benefits compared with gasoline and diesel fuel use (DeLuchi, 1989; Jones & Stokes Associates, Inc., 1993; Nowell, 1992; U.S. Department of Energy, 1991; U.S. Environmental Protection Agency, 1990).

Criterion 3. Potentially benefits Hawaii economy

Any fuel that may be produced locally from indigenous resources satisfies this criterion, insofar as the production requires local labor and expertise. Additionally, the potential for local employment in AFV-related businesses other than fuel production, such as vehicle manufacturing, conversion, or assembly, or battery recycling, must be considered when assessing economic benefits.

Criterion 4. Shows potential for locally available feedstocks to supply substantial volumes of energy

To qualify under this requirement, a fuel must show potential to be produced from local resources and be distributed to customers in sufficient volumes to meet large-scale demand. In addition, the vehicle technology associated with the use of the fuel must be appropriate for a significant portion of the transportation market.

Note that the long-term prospects for vehicle availability from original equipment manufacturers (OEMs) must be relatively strong for a fuel to satisfy this criterion. Alcohol, electric, natural gas (CNG and LNG (compressed natural gas and liquified natural gas)), and LPG vehicles are already commercially available. They are expected to be available in increasing numbers through the next few decades as manufacturers respond to the legislative and regulatory drivers discussed in Chapter 4. Biodiesel use does not require OEM participation, as it could be used in virtually unmodified diesel vehicles. Hydrogen vehicles are the furthest from commercial availability, but large research efforts are addressing both fuel cell and hydrogen internal combustion engine technology (Veziroglu and Barbir, 1992;

U.S. Department of Energy, 1993), so we assume that hydrogen vehicles will eventually be available. Therefore, vehicle availability prospects are good for all of the alternative fuels discussed here.

Criterion 5. Likely to be increasingly competitive with gasoline and diesel

Fuels which are expected to become increasingly competitive with gasoline and diesel are those whose real prices are expected to decline due to technological progress in their production. Fuels whose prices are more closely coupled to oil prices, such as synthetic natural gas (SNG) and LPG, rate lower than fuels which are less linked to oil prices.

Criterion 6. Provides flexibility and less uncertainty

A program to encourage alternative fuels will need some redirection as the program proceeds because of technological innovations and market forces. The program must therefore have flexibility. For example, it would be preferable to avoid requiring a large number of vehicles which could only be operated on a single alternative fuel ("dedicated" vehicles). If experience shows that the production and delivery of that fuel is economically nonviable, those vehicles would have to be converted, abandoned, or operated at great expense. As another example, it would be inadvisable to construct an alternative fuel production facility only to have the market for that fuel be short-lived, or even fail to materialize, should another fuel become preferable, or should vehicles for that fuel no longer be available.

To best meet this criterion, AFVs should be fuel-flexible. Examples include electric vehicles, since electricity is producable from many fuels, and methanol or ethanol fuel-flexible vehicles (FFVs). Converted LPG and natural gas vehicles that could be reconverted to petroleum fuels offer a lesser degree of flexibility.

Another factor under this criterion is that the market for the locally produced fuel should be relatively secure.

Criterion 7. Currently locally available in enough volume to supply demonstration programs

Any fuel which could be purchased currently from a local entity satisfies this criterion.

Criterion 8. Could be used in vehicles which are currently commercially available

Fuels for which AFVs are commercially available from major manufacturers rate highest under this criterion. Fuels for which AFVs are available as conversions or from small producers rate next highest, and fuels for which virtually no vehicles are commercially available rate lowest.

Criterion 9. Could be used to some degree immediately and with little effort and cost

Any fuel and technology combination which could be deployed soon, for which the vehicle technology is available and acceptable to the user, and for which the fuel could be made available at a reasonable price with minimum public subsidy, qualifies under this criterion.

Criterion 10. Has broad public support

The degree to which the public has demonstrated interest, enthusiasm, and support for any particular fuel is important, especially since public funds would be required to provide financial support for any alternative fuel program that aims at more than token market share. The relative degree of public support for each of the fuel options has been estimated by DBEDT in this study.

5.2 SCREENING ANALYSIS

To evaluate the fuel options which best satisfy Hawaii's energy goals as embodied in the criteria, the criteria were separated into two categories: "long-term strategic considerations" and "near-term considerations." Criteria 1 through 6 are "strategic," while criteria 7 through 10 are "near-term." The strategic criteria indicate which fuels are likely to be most beneficial to the state in the long run, while near-term considerations identify those options more easily implemented soon.

The screening analysis results are summarized in Table 5-1. The scope of this project did not allow supporting each rating with a detailed study. Qualitative ratings were based on current understanding. What follows is a discussion of the scoring of each fuel option.

5.2.1 ALCOHOLS: METHANOL AND ETHANOL

Discussion

Alcohol fuels may be produced locally both from biomass (such as sugar cane, banagrass, or tree crops) and waste products, such as green waste and municipal waste. Ethanol has already been produced from molasses in the state, and new efforts to produce ethanol from biomass and waste products are currently being undertaken by the Pacific International Center for High Technology Research (PICHTR), Arkenol, Cargill, Amoco, and others. DBEDT, the Hawaii Natural Energy Institute, and PICHTR have a number of programs underway to demonstrate methanol production from biomass. Some of the candidate conversion technologies are currently available, while others require more development (see Chapter 4).

Local production of fuel in sufficiently large volumes would provide a measure of energy security, insulating the Hawaii economy from disruptions in oil supply or price shocks. Additionally, use of methanol and ethanol produced locally has the potential to benefit the Hawaii economy, even if a state subsidy is required to make the price of alcohol at the pump competitive with that of gasoline or diesel. Energy crops could save agricultural jobs and create jobs in new industries. Hawaii's capacity to produce alcohol fuel is substantial. Chapter 7 further discusses indigenous biomass energy sources.

Table 5-1

Screening Analysis Results

Criteria Categories	Criteria	Alcohol	Biodiesel	Electricity	Hydrogen	NG	SNG	Propane/LPG
Long-Term Strategic Considerations	1. Potentially offers energy security to Hawaii[1]	+	+	+	+	0	-	0
	2. Potentially offers environmental benefits (including safety)	+	+	+	+	+	+	0
	3. Potentially benefits Hawaii economy	+	+	+	+	-	-	-
	4. Shows potential for locally available feedstocks to supply substantial volumes of energy	+	?[2]	+	+	-	-	-
	5. Likely to be increasingly competitive with gasoline and diesel	+	+	+	+	0	0	0
	6. Provides flexibility and less uncertainty	+	+	+	0	-	-	-
Near-Term Considerations	7. Currently available in enough volume to supply demonstration programs	+	-	+	-	-	+	+
	8. Could be used in vehicles which are currently commercially available	+	+	+	-[3]	+	-	+
	9. Could be used to some degree immediately and with little effort and cost	0	0	0	-	-	-	+
	10. Has broad public support[6]	+	+	+	0	0	0	+
Pass the Screen?		**Yes**	**Yes**	**Yes**	**No[4]**	**No**	**No**	**Yes[5]**

Notes:
1) A "+" score indicates that a fuel has a reasonable potential to be produced in substantial volumes from domestic resources. A "0" score implies that an imported fuel might offer increased security of supply and price stability compared with crude oil imports.
2) No analysis available on potential biodiesel production on Hawaii: Crop dependent, among other factors.
3) In this study, 'hydrogen vehicles' are considered to be internal combustion engine vehicles.
4) Although hydrogen scores well with respect to the strategic criteria, its score under near-term considerations is prohibitively poor and it will only be considered briefly in the remainder of this study.
5) Although propane scores poorly with respect to the strategic criteria, its score is clearly superior for near-term considerations and it will, therefore, be considered further in this study.
6) DBEDT estimate.

Imports are not expected to capture ethanol market share because adding the cost of transporting ethanol to the state is expected to render imported ethanol non-competitive. (Cost analyses in Chapter 8 support this conclusion.) Methanol, on the other hand, is typically produced outside of Hawaii from natural gas, at a substantially lower cost than methanol produced from fiber.

Utilization of local production capacity depends upon vehicle availability. Alcohol vehicles are already commercially available and the technology is more mature than that of any other alternative fuel vehicle except possibly LPG. The prospects for alcohol AFV availability into the future are not certain, but it is expected that vehicles would be available in increasing numbers in response to Energy Policy Act (EPACT) requirements, aggressive California programs, and other regulatory actions as discussed in Chapter 4.

Although costs are not currently competitive, alcohols are expected to be more competitive in the future due to technology improvements and increases in scale of use (affecting both production and distribution costs), coupled with increasing gasoline and diesel prices as environmental regulations, increasing regional and worldwide demand, and eventual increases in production costs drive up prices. Because the production costs of alcohol from biomass are more likely to fall than rise, we consider that alcohol from biomass is likely to be increasingly competitive with gasoline and diesel over the long-term.

Finally in terms of the strategic criteria, an alcohol strategy would be relatively low risk and flexible. This is because:

1) Light-duty alcohol vehicles are commercially available as FFVs.

   All of the light-duty alcohol vehicles being sold today are FFVs. They could operate on any combination of alcohol and gasoline from 100 percent gasoline to 85 percent alcohol. In the event that alcohol were not available, FFVs could be fueled on gasoline throughout the vehicle lifetime. Heavy-duty alcohol vehicles are typically dedicated, meaning that they must be fueled with the alcohol blend. Therefore, alcohol substitution in heavy-duty fleets is less flexible than alcohol use in light-duty fleets.

   An important complication is that commercially available vehicles tuned to one alcohol (say, methanol) cannot operate on the other (say, ethanol) without some adjustments to reset the engine timing and other parameters. Conversion of vehicles from one alcohol to the other has been discussed in Chapter 4.

2) A low-level alcohol blend strategy (e.g., gasohol) could be employed to balance alcohol supply and demand.

   In general, alcohol supply and distribution may be designed to flexibly meet increasing demand. In the case of overproduction, low-level gasoline/alcohol blends could be employed to create a market for alcohol produced in Hawaii. In the case of under-production, methanol imported from the west coast could be used before a local supply is available, and could also be used to supplement local supply to allow time for increasing production and distribution capacity in the state. Alternatively, FFVs could fuel with gasoline for a number of years until locally produced methanol becomes available.

Local production of ethanol could come on-line much faster than methanol. Ethanol plants may be built economically on a fairly small scale and have already been operated in the state, although none is currently in operation.

There is no reason that fuel distribution, which will be outlined in Chapter 6, should not keep up with fuel supply.

3) Biomass grown for alcohol production could be converted into electricity.

   Should biomass be grown in Hawaii for production of alcohols, and should electricity replace alcohol as the alternative transportation energy of choice, locally produced biomass would still have a market because it could be converted into electricity.

4) Alcohol is a front-runner candidate fuel for on-board fuel-cell (electric) vehicles.

   Methanol is one of the most practical hydrogen sources for use with fuel cells (DeLuchi et. al., 1991), which, some believe, are the best energy storage device for EVs. The methanol molecule (CH_3OH) is an efficient hydrogen carrier that may be delivered to and stored on-board a vehicle more easily than compressed hydrogen. Although the technological future of fuel cell vehicles is impossible to predict, should fuel cells become a viable and cost-effective means to power vehicles, local methanol production capability could be diverted from use in internal combustion (IC) vehicle engines to fuel cells.

In addition to satisfying the strategic criteria, the alcohol fuels score fairly well with respect to the near-term criteria. Alcohol-fueled AFVs built by major manufacturers could be deployed immediately, at no incremental cost for some vehicle types when compared to dedicated gasoline versions.[2] The use of alcohol as a motor fuel appears to have public attention and support. Alcohol fuel is currently available in the state and is being used in General Services Administration (GSA) and University of Hawaii (UH) vehicles on Oahu and Maui. Ethanol could be produced in the state in the near-term, perhaps within two to five years.

Conclusion

Methanol and ethanol satisfy all of the strategic criteria as well as some of the near-term criteria, and are thus evaluated further in this study.

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[2] FFV passenger cars are being sold in California at prices equal to or less than their gasoline counterparts. Although the FFVs, manufactured in small volumes, cost more to produce than conventional vehicles, the manufacturers price them competitively, indicating a vested interest in keeping the alcohol program alive. Alcohol vehicle sales give the manufacturers compliance options under the California LEV program, EPACT fleet market share, and a CAFE standards compliance margin. Alcohol-fueled transit buses are currently more expensive (by about 20 percent) than diesel buses.

5.2.2 BIODIESELS

Discussion

Biodiesel could be made in the state from local feedstocks, including waste oil from the fast food industry, waste from meat processing, and suitable oil crops. Currently, no biodiesel production exists in Hawaii.

The use of biodiesel blends as a substitute for petroleum-based diesel fuel could provide Hawaii with energy security in the heavy duty transportation sector. Because biodiesel blends could be used with minor modifications to engines,[3] biodiesel could power Hawaii's heavy duty buses and trucks, off-road equipment, and diesel-fueled marine vessels. Furthermore, because biodiesels are so similar to regular diesel, existing infrastructure could be used for their distribution and marketing (with the exception of requiring biodiesel-compatible materials for seals and hoses). Biodiesels might also be useful as fuel additives; the transesterified oils could potentially be used as additives to alcohol fuels to raise cetane levels (improving ignition) and to provide lubrication (alcohol lubricity is very low compared with gasoline and diesel fuel).

The features described above give biodiesel a very significant capital cost and implementation advantage over other alternative fuels. However, biodiesels are expensive to manufacture because fuel and feedstock costs can be high. Interchem Industries, Inc., which is very active in developing biodiesel for use in the U.S., has worked with Procter & Gamble to produce soy diesel in a full scale plant in Kansas City, Kansas. This plant could produce up to 25 million gallons of soy diesel per year. The current price (which depends on the volume purchased and the current price of soybeans) is about $2.50 to $2.60 per gallon (100 percent soy diesel, i.e., neat fuel) (Ayers, 1993).

If biodiesels could be produced locally at competitive prices, they would provide a measure of energy security while benefiting the Hawaii economy. Locally produced oils are now being produced for higher-priced markets, such as the food and cosmetic industry.

Hawaii's ability to produce oils in large volumes from oil seed crops is uncertain. The Hawaii Natural Energy Institute (HNEI) has never considered locally produced oil to be a mainstay fuel source. On a per acre per year basis, the energy contained in reported oil yields from oil crops (Reed, 1993) appears to represent only about 25 percent as much energy as is assumed for sugar or fiber crops, although relative productivities for similar locations in Hawaii are unknown.[4] Some oil crops may have the advantage of requiring minimal care, and some crops could, perhaps, be grown on marginal land. Local studies would be needed to ascertain the cost effectiveness of growing oil crops for fuel in specific volumes and areas. Until and unless such cost effectiveness is shown, there is little reason for Hawaii to import biodiesels except, perhaps, for demonstration purposes. Imported biodiesels, even used in 20 percent blends, would be quite expensive compared with regular diesel, and as biodiesel blends could be distributed through the current diesel distribution and marketing system and

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[3] Biodiesel can erode rubber, so rubber fuel lines or seals must be changed.

[4] The total plant energy content per acre actually includes (in addition to energy contained in the oils) energy contained in leaves, stalks, stems, etc.

used with minor modifications to engines,[5] there would be no need to import the fuel to support the development of new infrastructure or markets.

The costs of biodiesel would vary substantially depending on the feedstock, and would require careful study. Biodiesel from the major oil crops currently grown in the state, such as macadamia or kukui nuts, would be exceedingly expensive since these oils would otherwise be used in high-value, non-fuel markets. For example, the wholesale price of macadamia nut oil is about 15 to 18 dollars per gallon (Hawaii Kukui Nut Company, 1993). Transesterification to convert the oil to biodiesel would further increase the per gallon cost of this fuel. Biodiesel from soybeans, peanuts, sunflowers,[6] or other oil seeds might be manufactured in Hawaii at costs similar to those on the mainland, provided the meal fraction could be sold to the feed industry (Ayers, 1993).

The least expensive option would be to manufacture biodiesel from waste oil, such as the cooking oil discarded by fast food restaurants. This oil is currently sold for 12 cents per pound and shipped to Los Angeles, California for use in the feed industry (Ayers, 1993). Biodiesel production from waste oil in Hawaii could reach 500,000 to 700,000 gallons per year (Ayers, 1993). This volume would support a 20 percent blend in 150 to 200 transit buses, and would replace less than 1 percent of the diesel fuel currently used in the ground transportation sector and less than 0.5 percent of the total diesel fuel consumed in the state.

The Mason Research Foundation sees potential in Hawaii for oil production from the Chinese tallow tree. This tree produces seeds which consist of a thin, hard shell coated with a waxy fat, which contains an oil similar to tung oil. Oil yield per acre is high, about 12 barrels per acre per year, and after the oil has been extracted, the meal (comprised of the leftover shell and fatty coating) could be used as animal feed or fertilizer. The Chinese tallow tree, which typically reaches maturity in five years, has been found to be very hardy and could produce seeds in poor, waterlogged, and even salty soil. This tree has been identified by the U.S. Department of Agriculture (USDA) as a possible "industrial crop," and the Foundation has been studying the tree since the late 1970's. Studies have occurred in Hawaii for a number of years, partly with state support. The Chinese tallow tree has grown well in those locations in the state where it has been tested. However, the primary barrier to bringing Chinese tallow tree oil to market is the intense labor required for harvesting. The seeds will not fall off with shaking. Instead, each set of seeds must be individually clipped from the tree and the twigs manually separated from the seeds. The Foundation has been working to achieve a more economical method of harvesting. The Foundation has not yet evaluated the costs of fuel oil from the Chinese tallow tree, but expects that the oil would be sold as a food oil, where a higher price could be obtained, rather than as fuel (Boom, 1993).

To address the remaining strategic criteria, biodiesel is clearly flexible since it could be used in conventional vehicles. Therefore no risk exists of stranding vehicles without fuel, or investing in fuel production capacity without a market to serve. Biodiesel is also expected to become more competitive with diesel in the long run if oil prices rise and if the cost of producing crops could be decoupled from the price of petroleum fuels.

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[5] Again, material compatibility issues for fuel lines and seals may require some modification of the existing infrastructure and on-board fuel delivery systems.

[6] The per acre yield of sunflowers is about twice that of soybeans (Ayers, 1993).

The near-term criteria are partially satisfied by biodiesel. Vehicle availability presents no obstacle for this alternative fuel, and, were the fuel to be made available, it could be used in vehicles immediately with relatively low cost and effort.

Conclusion

Locally produced oils appear to satisfy the strategic criteria fairly well, although further work, outside the scope of this study, would be required to estimate how much biodiesel Hawaii might produce and at what costs. The role of locally produced biodiesel is not considered in detail in this study.

Imported biodiesels do not meet the strategic criteria of providing energy security (being produced from local resources) or benefiting the economy of Hawaii. Furthermore, unlike imported alcohol fuels (which might be needed to build up a population of alcohol-compatible vehicles and special infrastructure, thus facilitating the later distribution and use of locally produced alcohol fuel), imported biodiesel is not needed initially because special vehicles and infrastructure are not required for its use. However, imported biodiesel could be used to fuel a demonstration program and stimulate local interest and confidence. Such a demonstration could be a vital step toward achieving a business climate where industry might invest in biodiesel production in Hawaii.

5.2.3 ELECTRICITY

Discussion

Electricity is the most flexible power source for motor vehicles since it decouples vehicles from the original fuel. Electricity may be produced from many renewable resources, including wind, solar, geothermal, and biomass. In 1993, about 74 percent of Hawaii's electricity was generated by petroleum. The remainder came from biomass,[7] hydropower, wind, coal, and solar power (DBEDT, 1994). The current use of renewables varies by island. All of Lanai's generation is from petroleum, while almost 23 percent of Kauai's electricity is generated from renewable sources (DBEDT, 1994). On Oahu, petroleum generation represented about 74 percent of the mix. The use of coal for power generation on Oahu is increasing dramatically. For electric vehicle (EV) use to be most consistent with a goal of energy security and increased energy self-sufficiency, electricity production from domestically available renewables would need to increase. However, electricity produced from coal, which may offer increased security of supply and price stability compared to oil, would contribute to Hawaii's energy security goals as well.

Increased, cost-effective production of electrical energy from local renewable resources, rather than from imported oil or coal, would benefit the Hawaii economy. EVs could stimulate the local economy in other ways as well. EV conversions could be performed in the state to a greater degree than they are already and, potentially, EV assembly, component manufacture,

[7] Biomass-to-electricity conversion has occurred in Hawaii for years. For example, bagasse is used as a boiler fuel at sugar mills to provide process steam and electric power. Excess power is sold to the local electric company.

or ground-up vehicle manufacture could develop more in Hawaii.[8] Hawaii has a strong history of EV interest and development, and is one of five regions in the country to receive grants from the Advanced Research Projects Agency in 1993.[9] Infrastructure development and battery handling and/or recycling would create jobs, as well.

The quantity of electric power available would not hinder any EV programs in the near-term. On Oahu, due to purchase commitments with independent power producers, Hawaiian Electric Company (HECO) has nighttime operational problems resulting from low demand, and would benefit from the load-leveling that could occur with nighttime EV charging (Mulki and Waller, 1992). EVs could, therefore, increase operational efficiency of the utilities and provide benefits to rate payers. HECO has been actively supporting EV development in Hawaii. HECO and others in the state with an interest in EV development must resolve many institutional, financial, regulatory and other issues before there could be major adoption of EVs, however. It is beyond the scope of this analysis to resolve the many barriers facing deployment of EVs in Hawaii. Based on the current level of efforts being focused on EVs, and the substantial legislative and regulatory impetus for EV development, it seems safe to assume that EVs will be available in increasing numbers and with increasing consumer acceptance into the future.

EVs are commercially available, however, EVs are currently very costly compared with conventional vehicles (Terpstra, 1993). Current technological and other limitations (range and performance reduction, recharging procedures, batteries) constrain the market appeal of EVs to niches where limitations and inconveniences are acceptable, such as local shuttle buses and delivery vehicles. If research and development efforts are successful, the many other barriers facing EV deployment are addressed, and sale volumes increase, future EVs would be more cost-competitive with gasoline and diesel technologies, and would be an acceptable choice across a wider range of applications[10] than at present. The potential clearly exists for EVs to achieve substantial penetration in the long term and to contribute toward Hawaii's energy security.

EVs satisfy the near-term considerations in that they have public support,[11] electric power is available, and some vehicles are available. However, because EVs are currently very costly

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[8] Hawaii already has one organization that is marketing EVs, the Suntera Solar Chariot Company located in Hamakua on the island of Hawaii. An EV industry centered in Hamakua could provide alternative employment for those in the sugar industry. Suntera was recently awarded a loan from DBEDT in advance of receiving additional funds through the Hawaii Electric Vehicle Demonstration Project funded by the Advanced Research Projects Agency (see the following footnote).

[9] The Hawaii Electric Vehicle Demonstration Project (HEVDP), supported by a 24-month, $5 million grant from the Advanced Research Projects Agency (ARPA), as well as by private-sector support of about $6 million, will include 37 electric vehicles, including 3 buses, and manufacture of a commuter car, the Suntera SUNRAY, on the Big Island. The HEVDP will also include infrastructure development and data acquisition.
The current grant is expected to be the first in a series. Many view the potential multi-year funding for electric vehicles by ARPA to be an excellent opportunity to establish a "critical mass" of EV interest, technology, expertise, experience and infrastructure in the state.

[10] Possible applications for EVs in Hawaii are numerous, and take advantage of Hawaii's unique island setting, creating short average trip lengths in comparison to the mainland. Just a few possible applications that have been mentioned include:
- residentially based short-trip errand cars;
- home-work commuter vehicles;
- hotel-based rental vehicles for tourists;
- tour vehicles for parklands; and
- airport-hotel shuttles.

[11] Manifestations of support for EVs in Hawaii are numerous, and include:
- the hosting of the EV '93 Conference in Honolulu, which included technical and public programs and the "Pali Challenge," a demonstration of EVs over a 35-mile course that included the Pali.

(Terpstra, 1993) and the technology is still developing,[12] near-term implementation may be more challenging in these areas for EVs than for other alternative fuel options.

The recent experience of California with respect to EVs should be noted. EVs, as Zero Emission Vehicles (ZEVs), satisfy California's ZEV purchase requirement. However, domestic vehicle manufacturers continue to lobby to weaken this purchase requirement.

Conclusions

EVs satisfy all of the strategic criteria, some of the near-term criteria, and will be evaluated further in this analysis.

5.2.4 HYDROGEN

Discussion

Although hydrogen is primarily produced from fossil fuels such as coal and natural gas, hydrogen may be produced from renewable resources by water electrolysis.[13] Several other processes are being investigated internationally (Veziroglu and Barbir, 1992). Not yet commercially ready, but technically feasible, is hydrogen production from biomass gasification. Several pilot-scale systems have been demonstrated, and an important study performed by HNEI and the Florida Solar Energy Center found biomass gasification to be the most economical way to convert renewable resources into hydrogen (DeLuchi, et. al., 1991).

As with any alternative fuel which could be produced from locally available resources, hydrogen has the potential to provide energy security and economic benefits to the state.

The total amount of hydrogen energy which could be produced in the state has not been estimated as part of this study. With electrolysis, hydrogen production capacity is only limited by the supply of water and inexpensive electric power. Note that in a "renewable hydrogen" scenario, the supply of electricity from renewable resources is the limiting factor. Given the abundant salt water and renewable resources of Hawaii, we assume that a substantial percentage of the state's transportation energy demand could be met with hydrogen, and defer a quantitative evaluation to future studies.

The other aspect of whether an alternative fuel could supply a large portion of Hawaii's transportation energy is vehicle availability and distribution infrastructure. Hydrogen may be

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- frequent testimony in support of EVs at public forums on energy, which is often combined with comments on the types of lifestyles and land use patterns that could be associated with large-scale EV use;
- active, politically aware and well-informed advocacy groups, and
- articles on EVs in HECO's monthly newsletter to its customers.

[12] Just how EV technology and other issues affecting the implementation of EVs are developing was made apparent at the EV '93 Conference in Honolulu. Presentations were made by component manufacturers, vehicle assemblers and manufacturers, government agencies, coordinators of the five EV projects being funded by ARPA, land use planners, electric utilities and many others. It is clear that EVs face many technical, institutional, legal, regulatory and financial challenges. However, it is also clear that the EV field is highly dynamic, making estimates of the state of resolution of the many barriers facing the broad implementation of EVs highly uncertain.

[13] In order for hydrogen from electrolysis to be considered renewable, the electricity must be generated from a renewable source: biomass, solar, wind, OTEC, or others.

used to fuel internal combustion engine (ICE) vehicles or fuel cell vehicles. In this study we consider only ICE hydrogen vehicles which are thought to be closer to commercialization than fuel cell vehicles (McKinley, 1993).

Of all the alternative fuels discussed in this study, hydrogen is the farthest from commercialization as a motor vehicle fuel. While hydrogen use in motor vehicles is impeded by the same factors that affect the other alternative fuels (lack of infrastructure, immature vehicle technology, and, more importantly, economic disadvantages), the most apparent reason for hydrogen vehicle commercialization lagging behind other alternative fuel technologies is the relative difficulty of storing hydrogen.[14] Storage of hydrogen, particularly on-board, poses unique technical challenges.

Hydrogen could be stored as a compressed gas, a cryogenic liquid, or as a gas bound to metal hydrides or absorbed on activated carbon. All of these technologies are expensive on-board a vehicle, and to obtain ranges similar to conventional vehicles, would require larger storage volumes due to the physical properties of hydrogen (DeLuchi, 1989). For example, although a pound of hydrogen contains over twice the energy of a pound of natural gas, the density of hydrogen is almost one-eighth the density of natural gas under standard conditions. Therefore, it is more difficult to store energy on board a vehicle as hydrogen compared to natural gas. To store adequate amounts of fuel on a vehicle, compressed gaseous hydrogen would theoretically need to be stored at 10,000 psi (DeLuchi, 1989), roughly three times the typical pressure used for natural gas storage in vehicles. Alternatively, as a cryogenic liquid, hydrogen must be stored at about -425°F, compared with liquefied natural gas temperatures of about -238°F. Such low temperatures require super-insulated, bulky storage vessels. While technologically feasible, hydrogen storage on-board presents significant economic and practical disadvantages.

For the reasons outlined above, hydrogen vehicles are seriously handicapped with respect to near-term implementation. At this time, only a very limited number of vehicles have been modified to run on hydrogen, serious storage problems remain to be solved, and the costs associated with hydrogen vehicle operation are very high.

While costs are currently very high for hydrogen production (especially from renewable resources), distribution, storage, and vehicle operation, technological improvements are expected to bring the costs down significantly over the next few decades (DeLuchi, 1989; DeLuchi et. al., 1991; Veziroglu and Barbir, 1992), and we assume that hydrogen vehicles would be increasingly competitive with conventionally fueled vehicles.

Finally, the flexibility of a hydrogen program is unclear at this time. Hydrogen engines appear to have the potential to be fuel-flexible (DeLuchi, 1989), a feature which would greatly increase the flexibility of a hydrogen strategy. Hydrogen could be used in vehicles or in stationary fuel cell power plants as these become competitive. Provisionally, the flexibility of a hydrogen program appears to fall between the flexibility of an alcohol program and the less-flexible natural gas option.

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[14] Engine technology does not present a substantial obstacle. Gasoline engines have been successfully modified to run on hydrogen and have achieved thermal efficiencies 15 to 50 percent greater than gasoline operation. The best performance has been found using direct injection of liquid hydrogen (DeLuchi, 1989). Hydrogen vehicles have been developed in limited numbers for research and as prototypes by Daimler-Benz and BMW (North, 1992).

Conclusions

Hydrogen rates well with respect to the strategic criteria. This fuel could potentially be produced in Hawaii in large volumes from local resources and used to fuel motor vehicles, offering the state energy security and economic and environmental benefits. The fuel is likely to be increasingly competitive with gasoline and diesel, although the time frame for this competitiveness is unclear. A hydrogen program would probably be somewhat flexible, as the fuel may be used in ICE or fuel cell vehicles, and ICE vehicles could possibly be FFVs.

However, hydrogen motor vehicles are far from being commercially ready. Advances and cost reductions are needed in hydrogen production from renewables, storage and distribution, and vehicle applications, before it could be considered a real option in the alternative fuels arena. It is premature to consider hydrogen infrastructure, policies and costs in detail in this study.

5.2.5 NATURAL GAS AND SYNTHETIC NATURAL GAS

Discussion

Natural gas is a popular alternative fuel on the mainland because of the availability of inexpensive gas from wells, combined with the efficient, existing pipeline distribution network. The costs of natural gas infrastructure have been distributed over the entire rate-base of over 55 million residential, commercial, and industrial users (American Gas Association, 1992). These advantages result in the price of uncompressed gas to the refueling station being less than one half of typical wholesale gasoline prices on an energy equivalent basis.[15] This low energy cost in part offsets the high capital costs of compressor stations or liquefaction facilities, natural gas vehicles, and the cost of the energy required to compress or liquefy the gas. Currently, on the mainland, natural gas and methanol are the prime competitors for the EPACT market. The economics of alcohol on the mainland are characterized by higher fuel costs than both natural gas and gasoline on an energy equivalent basis, and lower capital costs than natural gas.

In Hawaii, however, natural gas has significant disadvantages. First, Hawaii has no natural gas reserves or importation infrastructure (see Chapter 4's discussion of synthetic natural gas). Because of this, natural gas in Hawaii would be considerably more expensive than natural gas on the mainland.[16] The natural gas used in Hawaii currently is SNG, a product of oil refining. Natural gas vehicles would not run on SNG, so natural gas produced locally from biomass or waste feedstocks (as was described in Chapter 4), or natural gas imported as a cryogenic liquid (LNG) would need to be provided for vehicles.

[15] Estimate based on uncompressed natural gas at 30 cents per therm, a typical price a transit district (at a non-core rate) would currently pay in California. Wholesale gasoline prices of about 70 cents per gallon are consistent with 1991 and 1992 California prices.

[16] The total production capacity of the existing SNG plant is 150,000 therms (HHV) per day, about 5 percent of the energy used for ground transportation in 1990. SNG is currently priced at 62 cents per therm, about twice as much as natural gas used for transportation on the mainland. This price may be more of a function of the price of competing fuels than of cost. The cost of SNG production was not researched as part of this study.

Imported LNG, if necessary, could supply large volumes of fuel, but at a high cost[17] and with less energy security and economic benefits compared to a fuel produced from local resources, especially if LNG was not produced in the United States. Imported natural gas would carry the cost of shipping, which would be very high for the small volumes Hawaii would import to support an early vehicle program. Without low-priced gas to offset high capital costs for distribution facilities, compressors, refueling equipment and vehicles, operators of natural gas vehicles in Hawaii would bear a very high cost burden.

The potential capacity for local production of natural gas from waste is small.[18] Methane could be produced by biomass gasification in larger quantities; however, given similar production costs, alcohols would be preferable to methane because liquids are easier (and cheaper) to distribute and store than gases.

Natural gas vehicles do not provide the flexibility of the alcohol vehicles. They are typically dedicated, rather than fuel-flexible, to achieve adequate fuel economy and range, and therefore could not be operated on another fuel if natural gas were in short supply.

For the near-term, natural gas rates well in terms of vehicle and fuel availability. However, it does not rate well in implementability with little effort and cost, because the cost of the fuel in Hawaii would be high, it is costly to compress gas and transfer it on to a vehicle, and vehicles themselves are costly.

Conclusions

Natural gas does not satisfy the strategic criteria. Even if technological advances reduce the cost of production from renewables, waste would not supply enough fuel to meet a large demand, and biomass-derived natural gas is unlikely to be competitive with biomass-derived alcohols once infrastructure and vehicle costs are included. Imported gas does not compare well with fuels produced from local feedstocks under the strategic criteria. It is not feasible to use SNG in vehicles. For these reasons, we do not conduct a detailed assessment of natural gas in this study.

5.2.6 LIQUEFIED PETROLEUM GAS (LPG/PROPANE)

Discussion

Liquefied petroleum gas, also commonly known as LPG or propane, (see description of fuel in Chapter 4) is currently in favor as an alternative fuel on the mainland for several reasons. The fuel is typically less expensive than gasoline because it is available in increasing amounts due to an expanding natural gas industry (propane is extracted during natural gas processing and oil refining). Requirements for reduced gasoline volatility in several areas on the mainland, also require increased butane removal. (Butane may be added to LPG in small amounts

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[17] The Hawaii Energy Strategy Project 2: Fossil Energy Review and Assessment (1993) estimated the costs of an entire LNG production, transportation, and terminal system at $3.2 billion.

[18] The report Methane Resource Assessment for Hawaii, (Department of Planning and Economic Development, 1984), concludes that a maximum of 3.415 billion Btu or 28,496 gallons gasoline equivalent per day could be provided with methane produced from animal wastes, landfills, and wastewater treatment plants. This translates into a 2 percent reduction in 1992 ground sector fuel use.

without violating the commercial specification). Also (see discussion in Chapter 4), LPG is a familiar fuel which has been used in forklifts and utility vehicles for many years.

Hawaii currently consumes about 30 million gallons of LPG per year, most produced by local refining, but some imported (Freeman, 1992). If dedicated solely to vehicles, this volume would displace about seven percent of the total ground sector fuel consumption projected for 1996. However, Hawaii LPG is currently used for cooking, water heating, and other fueling needs, particularly in remote areas. It is not clear how these non-transportation needs would be met if LPG were redirected to vehicle use. Since Hawaii already imports propane to satisfy existing demand, imports would have to increase to supply the transportation sector. Without a local natural gas supply, LPG does not score well under the energy security criterion.

LPG vehicles are commercially available, typically as standard gasoline vehicles sold in "conversion-ready" form. The upfitted vehicles are sold at costs somewhat higher than comparable conventionally fueled vehicles. Vehicles are dedicated, rendering a propane strategy relatively inflexible (although "reconversion" is possible). However, with fuel and vehicles available at low incremental cost compared with gasoline, propane could be used to some degree in vehicles immediately with little cost and effort. For example, the City and County of Honolulu has 139 LPG-fueled vehicles (Miura, 1994).

Conclusions

LPG does not meet the first criterion of providing energy security for Hawaii as well as some other alternative fuels. It cannot be produced from indigenous resources and must either be produced locally from imported crude oil or imported. However, imported LPG may offer increased supply and price stability compared with imported crude oil. A LPG strategy for Hawaii would involve importing a significant amount of LPG, expanding local refinery production, or redirecting LPG from existing users. Because engines and vehicles are available and publicly accepted, and because The Gas Company supports an active LPG vehicle market in Hawaii, LPG vehicles will likely fill much of the initial EPACT demand for alternative fuel light trucks and vans in Hawaii. However, an imported fuel does not well satisfy the "energy security" goal. LPG does not satisfy the third criterion of benefiting the Hawaii economy to the same degree as a fuel which could be produced on a large scale locally. A number of jobs could be created to retrofit/convert vehicles to LPG, but the benefit of a LPG conversion industry to the Hawaii economy would be much smaller than the benefit of a local fuel production industry. Furthermore, LPG vehicles are dedicated, not offering the flexibility of alcohol FFVs or electric vehicles. Therefore, although LPG provides environmental benefits and shows potential to supply a large volume of fuel (under an import scenario) at competitive costs, government measures to increase transportation use of LPG will not be a focus of this study.

However, it is important to note that LPG has already been implemented. LPG vehicles have been operated in Hawaii for years. Once EPACT tax deductions are taken into account, upfitted LPG vehicles are cost competitive with gasoline vehicles, and The Gas Company has stated that it would price LPG to be competitive with gasoline on an energy equivalent basis (Freeman, 1992). For these reasons, LPG is finding its own niche in Hawaii fleets.

5.2.7 CONCLUSIONS OF THE SCREENING ANALYSIS

Table 5-1 shows the results of the screening analysis. Fuel options were rated in relation to each other, with a "+" as the top score, a "0" as the next best score, and a "-" as the lowest score. Note that the use of "0" as one of the symbols is not intended to indicate that a fuel option rates equal to some undefined baseline; it simply indicates a rating in between good (+) and not-so-good (-). Fuel options receiving all "+" ratings for the strategic criteria "pass" the screen. A "pass" indicates that large scale use of these fuel options appear in the long-term to be the most beneficial for Hawaii, and that these fuels should therefore receive the most attention and support from the state. The ratings are based on our current understanding of technology status, the political and economic environment, and other factors. This screening analysis should be evaluated periodically.

What emerged as the key factor in this comparison of options was whether the fuel could be produced in the state from locally available feedstocks at a low enough cost that the same fuel, imported, was unlikely to capture market share. Fuels expected to be producible from local resources and competitive with imports received high ratings for energy security and economic benefits, two major strategic criteria.

Fuels not passing the screen may still have a role in Hawaii's alternative energy future. However, programs to introduce alternative fuels into the transportation sector are costly and require public support. Therefore, it is important to identify which fuels are most consistent with the state's goals. The majority of the state's effort and resources could then be focused on the introduction of those fuels which are expected to provide Hawaii with the most benefits in the long-term. Other alternative fuels are acceptable, but may not warrant the same level of state encouragement.

We conclude that alcohols, electricity, and to a slightly lesser degree biodiesels deserve the most public attention and state support. These fuels meet strategic criteria by having the potential to be produced from indigenous resources, providing Hawaii with increased energy security and benefiting the state economy. Alcohols and electricity have the potential to supply a substantial volume of transportation energy using local feedstocks. In addition, vehicles using these fuels (including conventional vehicles in the case of biodiesels) are expected to be increasingly available. Strategies employing any of these fuels would be comparatively low-risk and flexible, and the costs of these fuels are not linked to oil prices (assuming electricity is generated from renewable resources). Finally, all of these fuels could provide environmental, health, and safety benefits if properly handled and used. In light of these considerations, the remainder of this report will focus on these fuels.

Hydrogen rates well in terms of the strategic criteria, but poorly under near-term considerations. However, as hydrogen appears to be a potentially strong candidate for eventual large-scale use in Hawaii's transportation sector, we recommend that hydrogen production from renewables, hydrogen storage, and hydrogen vehicle technology be followed closely by the state.

In addition, LPG is an alternative fuel with a role to play in Hawaii. Although LPG does not fully satisfy the strategic criteria, it is one alternative fuel that could be implemented easily and at low cost. In addition, it has support from the local LPG industry. Therefore, alternative fuel requirements are likely to result in some LPG use, and the ease of LPG implementation could provide other alternative fuels programs with momentum and added credibility.